HE PROFESSION OF THE MECHANICAL OR DYNAMICAL ENGINEER.

AN

INAUGURAL ADDRESS

BEFORE THE

Sheffield Scientific School

OF

YALE COLLEGE,

Delivered October 5, 1870.

BY

WILLIAM P. TROWBRIDGE,

PROFESSOR OF DYNAMICAL ENGINEERING.

REPRINTED BY PERMISSION OF THE AUTHOR

FOR

GRATUITOUS DISTRIBUTION TO THE CORRESPONDENTS OF THE PUBLISHER.

PHILADELPHIA:

HENRY CAREY BAIRD,

INDUSTRIAL PUBLISHER,

406 WALNUT STREET.

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NOTE BY THE PUBLISHER.

MANY years devoted to an investigation of the problems of Social Science—that body of knowledge which concerns itself about the laws which govern man in his efforts to improve his condition—added to an experience, by no means limited, in the publication of books of an industrial or technical character, naturally combined to attract the attention of the undersigned to Professor Trowbridge's Inaugural Address on Dynamical Engineering, herewith republished. A perusal of it convinced him that it was one of the clearest, most original, and most important papers on education which had ever appeared in this country. He therefore believed that it was of the utmost importance that it should be placed in the hands of every educator, engineer, and mechanic, and, indeed, of every intelligent head of a family in the land. Such being his conviction, he felt it his duty to take measures to give it a more widely extended circulation than it had had, and especially among that large and progressive body—the scientific and practical men—so many of whom he takes pride and pleasure in numbering among his correspondents, customers, and friends. To this end he sought and obtained permission of the author for the publication of the present edition, which is now offered to the public.

It is hoped that every one—certainly every engineer—into whose hands a copy of it falls will read it for himself, and form his own conclusions in regard to it; but the undersigned cannot resist the temptation to call particular attention to the extreme beauty and felicity of the respective definitions of *Civil* and *Mechanical or Dynamical Engineering*, and the consequent systematic separation of the subjects. These definitions once adopted, any particular subdivision of either of these branches will be caused to fall naturally to the understanding, and almost without any effort of the mind, under its appropriate head, and into its proper classification. Of the author's statement of the respective relations of theory and practice to each other, and to THE MAN, in making a real engineer, it cannot but be conceded that it sheds a flood of light upon this great educational, industrial, and social question.

The late Peter Barlow, the eminent engineer, after a full and systematic examination into the various facts regarding the power of man to labor, his capacity in directing the forces of nature, and their power and applicability to his uses and wants, placed on record, as the result of his investigations and convictions, these memorable words:—

"It seems, indeed," he says, "a reasonable inference, from all that has now been stated, that man was designed by his maker for a higher principle of action—for the exercise of skill, and for invention; to regulate the action of the lower animals to the purpose of labor; to convert air, fire, and water to his service, and only where skill and direction are required, to become himself a mechanical agent."

Let the nations take note! Let political economists, educators, statesmen, politicians, journalists, and all men who would mould public opinion, or govern the State, understand that the true road to civilization lies in the direction of the adoption of these ideas, and putting them in practice. Let public policy and education alike combine for the realization of such a result, and THE PEOPLE will reach a point in prosperity, comfort, and happiness, and THE NATION such power as the world has never hitherto seen, and will envy and emulate. Then shall we present an example of men, women, and children in the truest and best sense of the word FREE, because no longer under the dominion of poverty, and the ignorance and misery which are its accompaniments.

HENRY CAREY BAIRD.

Philadelphia, January 16, 1871.

INTRODUCTORY NOTE.

In the Sheffield Scientific School at New Haven the importance of Mechanical Engineering as a branch of learning has for many years been recognized; but recently the income of the School has been sufficiently enlarged for the maintainance of an additional professorship to be solely devoted to this department of science. To such a chair Professor William P. Trowbridge was invited—a graduate of West Point, formerly of the U. S. Coast Survey, and recently of the Novelty Iron Works in New York. He accepted the position, and on assuming its duties delivered the following inaugural address in the presence of the benefactors, officers, and students of the Scientific School.

To those who are interested in knowing the particulars of a scheme of study laid down in accordance with the principles of this address, a special circular will be sent on application.

The Governing Board of the Scientific School in publishing this address would make grateful mention of another valuable gift received in connection with the accession of Professor Trowbridge. The authorities of the Novelty Iron Works have presented to the School a collection of drawings, numbering several thousands, which have been accumulated in that establishment during the last quarter of a century, and which exhibit, entire and in detail, the multiform mechanical structures there manufactured.

New Haven, Connecticut, Nov. 1, 1870.

ADDRESS.

The discussions which have arisen during the last few years in relation to the necessity of more thorough and systematic education in the applied sciences, have had their real origin, more, perhaps, than from any other cause, in the rapid development and progress of the arts and industries due to the applications and uses of machinery.

To this cause may be attributed not only the intense commercial and internal business activity which now prevails, but also the absolute existence and growth of many of the sciences which excite public attention: and the subject of *Mechanical Engineering* has thus become one of such varied and extended usefulness, embracing also, in itself, the applications of such a wide range of the Mathematical, Chemical, and Physical Sciences, that it is natural that popular interest should have become excited in the introduction of this study in our institutions of learning.

Coming from active business life, where the necessities and demands for the services of young men of higher standards of qualification are most seriously felt, I feel that I may express the acknowledgments which I know to be entertained by manufacturers and business men, to the Governing Board of this Institution for the comprehensive and liberal manner in which this question has here been met.

As this is the first instance in this country, in which an institution of learning has adopted a systematic course of instruction having for its object, *exclusively*, the preparation and training of young men for the pursuit of this comparatively new profession, I propose to direct your attention, this evening, to several points, which, it appears to me, may be appropriately dwelt upon in connection with the subject.

First. As to what constitutes *Mechanical or Dynamical Engineering*—its relations to Civil Engineering, and other applied sciences, the nature of the subjects to be taught, and the character of the instruction to be imparted.

Second. The relations of theory and practice, considered as modes of preparation, or training, for the pursuit of the profession.

Third. The course of special studies to be pursued; the relations of these studies to each other; and their applications or bearings, in regard to the uses which they subserve.

Fourth. The channels of useful employment open to engineers in this profession, and the beneficial influences which must be exerted in various ways by the numbers of highly educated young men whom it is to be hoped this Institution may send out into business communities.

1. What is Dynamical Engineering?

No one who has watched the progress of the general science of Engineering, can have failed to notice that it has become a very complex science in its numerous applications, both in theory and in practice. In a general sense it embraces Civil Engineering, Mining Engineering, Mechanical Engineering, Hydraulic Engineering, and Military Engineering, besides many special applications of Physics, Chemistry, and Mechanics, in the arts and manufactures, such as relate to the preparation of metals, refining, distillation, the manufacture and distribution of illuminating gas, etc., to which no special appellations are given; so that the term "Engineer" now carries with it no definite meaning, although it is in very general use. All these branches of Engineering science are based to some extent, though not entirely, on the same general principles; but they are so diverse in the applications or uses of those principles, that no one person can attempt to master thoroughly the theory and practice of more than one of these special branches. This condition of things has arisen in part from the rapid development and progress of that branch which has received in this country the name of *Mechanical Engineering*.

This branch of engineering may be said to embrace within its range of applications all the natural sciences which relate to the construction and employment of machinery for utilizing the natural sources of power in the performance of useful work, and the construction and use of all varieties of machinery driven by those sources of power, for mining, civil engineering, commercial, industrial, and manufacturing purposes. To this branch of applied science we owe the marvellous progress or changes made during the last few years in all the social conditions and relations of civilized life, such as the changes in modes of transportation, the improved facilities in mining, and the preparation of iron, steel, and other materials for the civil engineer and architect; and also the facilities afforded for manufactures of infinite variety and uses.

Under this condition of rapid development, the scientific literature of late years, as far as engineering has been concerned, has been largely, and at some periods almost exclusively, devoted to this new and progressive science.

From this circumstance, and from the fact that the practice of the profession has been confined to a certain extent, to persons connected with large engine or machinery establishments both in this country and in Europe, considerable confusion of expression has arisen in the use of terms relating to it. In some institutions of learning, for instance, partial courses of instruction have been instituted under the head of "*Mechanics and Engineering*," "*Applied Mechanics*," "*Industrial Mechanics*," and "*Applied Mathematics*." While in the actual practice of the profession the terms "Practical Engineering," "Steam Engineering," and "Mechanical Engineering," have been variously and indiscriminately employed.

From these circumstances a necessity has arisen for more clearly defining the limits, both in theory and practice, of the two great branches of engineering which comprehend and embrace all others, civil engineering and mechanical engineering. And it has become evident that either the whole science of modern Engineering must be considered and taught as one science embracing all these specialties, or a proper division and distinction should be adopted, having reference to the elements of theory and practice in these two branches.

In an institution where these elements are to be taught, there should be definiteness of ideas as well as of expression. It has been properly assumed here that such a distinction should be made; and two courses of instruction will be open to the student according to his desire to pursue one or the other branch of the profession.

The division between these courses may be broadly and definitely marked, from the nature of the subjects to be most prominently taught, and the range and character of their application.

Civil Engineering embraces, as its objects especially, works of a general or public character, general surveys, the building of roads, railroads, canals, bridges, public buildings, water-works, the improvement of rivers and harbors, the construction of docks, piers, dams, and reservoirs.

Mechanical Engineering is applicable rather to works connected with private enterprise, such as the designing and construction of steam machinery for the purposes of navigation and transportation, the adaptation of such machinery to mills and factories, the construction of water-wheels, the fabrication of materials, iron, steel, and brass, for the purposes of the engineer, the architect, and manufacturer; and the manufacture of implements and machinery for agriculture, for mining, and for domestic purposes.

But the prominent feature of Mechanical Engineering, that which contributes more than any other to elevate it to the rank of a liberal or learned profession, and at the same time separates it from the science of Civil Engineering, is, that all its operations relate to *power*, *motion*, and *work*.

Civil Engineering structures are based on the principles of *statical* equilibrium. They are passive. Freedom from motion, permanent rest, and immobility, are the objects most sought; while in Mechanical Engineering, energy, velocity, the movement of masses in the performance of useful work, are the controlling features, without which this branch of applied science could not have existed. And hence it embraces the entire field of Dynamical Science—the Science of Motion and Power.

The term "*Mechanical Engineering*," applied to such a profession, although that which is in most current use, is not popular, even with those who practise it, because it is not fully indicative of the nature of their calling nor of their acquirements.

This difficulty arises from the fact that the term *Mechanical* is not employed in the sense which it would derive from the word *Mechanics*, as descriptive of a science of mathematically applied principles: but from the more restricted sense in which it is used to designate the work of construction of a machine, and the labors of the artisan or mechanic. It originated in the large machinery establishments, and at first referred especially to the manipulations necessary to produce and combine the material parts of a machine, rather than to the intelligent application of the laws of Statics and Dynamics, in designing and adapting machinery for the performance of specific work. In the sense derived from the word mechanics as a science, civil engineering is also a mechanical science; the only difference between this and mechanical engineering being that one is based on the principles of *Statics*, and the other upon *Dynamics*. These considerations would have little importance if the questions involved were merely those of words; but as before remarked they involve confusion of ideas, especially in the popular understanding of the subject. It has not, always, been deemed essential, for instance, that a mechanical engineer should be thoroughly acquainted with the *science* of mechanics, and his calling has been regarded as a trade or an art, rather than as a learned profession; as depending more on knowledge and experience in manipulations, or the labor of the hands and the use of tools, than on the exertions of the intellect.

For these reasons it seems desirable that a more appropriate designation should be found for a profession which demands the highest power of the mind for its successful prosecution: and the term "*Dynamical*" is one which would not only express the peculiar characteristics of this profession, but would also serve to distinguish it clearly from Civil Engineering.

In this connection it may be remarked that the whole subject of the application and use of machinery may be divided into two parts or divisions: one embracing the laws of *pure mechanism*, and not depending in any manner upon the sources or amount of power used, nor especially upon the quality and strength of materials; but rather upon the ingenious contrivances and combinations of the parts of a machine to produce a specific effect. This division embraces all that useful class of inventions which now form the most indispensable aids to human labor; such as machines for sewing, spinning, weaving; machines for making nails, screws, bolts, nuts, &c.; tools for turning and shaping materials, and thousands of others, the mere mention of which would form an extended catalogue.

These, depending upon mechanism alone, require for their production only a sort of natural inventive talent, which is brought out when occasion requires. Under the wise protection of patent laws, this talent is constantly stimulated even in uneducated minds; and there is now scarcely a department of human industry which does not avail itself of useful inventions for multiplying labor, or producing certain results which could not otherwise be effected.

This branch of the subject, however, does not involve the idea or necessity of engineering. It properly belongs to the *mechanical* part of the profession.

The other division of the subject depends upon the intelligent application of the SCIENCE of MECHANICS in developing, utilizing, controlling, and adapting those forces of nature which are employed in driving steamships, mills, factories, railroad trains, and forges: involving also the sciences of Chemistry, Physics, and Metallurgy, and requiring the application of all these sciences combined. The prosecution of this branch of the subject assumes the character of a *profession*, and calls for the highest degree of theoretical training for the solution of its difficult problems.

2. Theory and Practice.

The chief obstacle to the introduction of full and thorough courses of study in the applications of mechanical science in institutions of learning, heretofore, has existed in popular misconception on these points, which has given rise to a mistaken preference for purely practical training, and a disregard of the higher value of preliminary instruction in the sciences which lie at the foundation of all successful practice.

Pure Mechanism is a subject so entirely practical that in this country nearly every man is an inventor, if occasion requires; and particular machines of great value and public benefit have been devised by men who have a genius for invention, but are not learned in the sciences. And this general aptitude for devising mechanical means to accomplish special ends, the skill acquired by all good mechanics in the use of tools, and the peculiar knowledge of workmanship and manipulation which can be attained only by practice, have given to the old issues and controversies between theory and practice more apparent real foundation in employments connected with machinery than in any other.

The true question at issue is how best to prepare young men during the first four or five years of their career for the useful occupations to which they may thereafter be called in the general practice of their profession.

This is a question which chiefly interests parents who wish to give their sons the benefit of the most efficient and useful instruction during the few years preceding the time when they are to choose and act for themselves. It interests students who are personally the most concerned. It interests teachers who desire to confer every possible benefit on their pupils; and it concerns, in an important degree, the public who are to be the employers of the young men who present themselves as qualified for responsible trusts and positions.

In choosing between the practical and theoretical systems of instruction, two courses are open; one, an apprenticeship in a machinery establishment, and the other a course of study in a school of applied science; each to occupy the period of life from the age of seventeen to twenty-one or twenty-two years.

From which of these courses will a young man emerge best prepared for subsequent advancement and usefulness?

1. The practical course ignores books and the study of the natural sciences. A boy on entering a machine-shop is placed at some simple mechanical work, the use of the file, or chipping hammer, or lathe. In two or three years he may acquire experience in finishing the finer parts of machinery. He will be fortunate if at the end of four years he is

entrusted with the fitting, "setting up," and operating the most simple engine or machine.

During this time he has learned only an art, and the use of tools, with perhaps a few simple mechanical combinations. Beyond these he has received no instruction, unless, actuated by unusual ambition and energy, he has devoted his evenings, after days of hard labor, to study. He must otherwise remain ignorant of mathematics, of drawing, the laws of mechanics, and of physics and chemistry. He has but little opportunity of studying the general arrangements and adaptation of machinery to various uses; and in learning the principles of a science which treats of the development, application, transmission, and control of Power, in the most efficient and economical manner—and in which the laws of heat, pressure, velocity, friction, the momentum of masses, must be regarded as specific quantities, to be mathematically and numerically determined—he has made no progress.

If he obtains a position in the drawing or designing room, of such an establishment, he may acquire a knowledge of drawing, but his time is absorbed in making tracings and working drawings under the direction of superiors who have no time to impart general instruction in the fundamental principles of the work on which he is engaged. A shop, or machinery establishment is a business establishment, not a school of instruction, and it is rather a favor to young men to allow them the limited privileges of such information as they may acquire through their own observations and experience.

Such a course may lead to a high degree of skill and excellence in the specialties of one establishment, but even in such a case the knowledge is gained by imitation. New problems even in that specialty—which involve new forms and dimensions—are apt to be discussed and solved by reference to the nearest example or precedent.

There are instances of men who have reached an enviable degree of excellence in the profession, whose first years have been passed in the workshop; but such men have invariably possessed peculiar qualifications of industry and application; and while enjoying the opportunities of practice, they have found time for the study of the sciences; and have become learned in theory as well as skilful in practice. Such men are rare; and while they furnish examples to be imitated, they are exceptions to the general rule.

Purely practical men frequently commit errors which are disastrous in their consequences, from a want of knowledge of some general principle, the understanding of which would have led to more definite and correct reasoning, and less dependence on that sort of intuitive knowledge which they to a certain extent acquire—"the rule of thumb." Every new problem is solved to a certain extent by trial, which involves all the expense and risks that universally attend experiments.

Under such circumstances advancement must be slow and tedious. Years of life are spent in acquiring knowledge that is already within reach in the recorded labors and experiences of others, and embodied in laws and general principles applicable to every case of practice that may arise. A knowledge of standard works on the various applications of machinery, and the ability to read and comprehend the current scientific literature of the day, are often found to be essential to success only after the period of life, and the opportunities for acquiring habits of study, have passed.

Innumerable instances might be given to illustrate the truth of these statements. In conversation with an intelligent young mechanic a few days since in New York, I alluded to the Sheffield Scientific School, and especially to the project of a course of instruction in Mechanical Engineering. My object was to draw from him his views on this very subject of thoretical and practical training. As he was a man of extensive practical experience, of clear judgment, full of resources, self-reliant, and altogether one of the best practical machinists in this country, I had great confidence in his judgment, and awaited his response with considerable interest. He replied to my remarks by relating an incident in his own life, informing me at the same time that it was the first time he had ever "told this story on himself."

Shortly after he had completed his apprenticeship in one of the large machinery establishments of New York, and while still in the service of that establishment as a machinist, he was selected by the firm to take a Cornish Pumping Engine to the coal fields of Maryland, and there to erect it in a certain mine for which it had been manufactured. He received no special instructions for his difficult task, and was too much elated, and too confident in his own acquirements, to imagine that he should meet with any difficulty.

On arriving at the mine he found no mining engineer to give him information, but he was told where he would find the shaft; and was informed that the contract with the Iron Works was for the engine and pumps to be erected complete and in working order. He had never seen a coal mine, and had formed no conceptions in regard to mining operations. On looking for the shaft, he found, to use his own expression, a black hole in the ground about twelve feet square; and was told that it was two hundred and fifty feet deep. Scarcely daring to approach the edge of such a formidable black hole, and yet knowing that part of his machinery must go down that hole to the bottom, to be connected with the engine at the surface, his courage and enthusiasm began to abate, and he felt, for the first time, quite serious over his prospects. After reflecting on the situation, and having too much pride to return home to ask for information, he decided upon a plan for getting out of his difficulties. He had learned that several weeks must elapse before the mine would be ready for his machinery, and accordingly started by the next train for Philadelphia, where he had friends who he knew might assist him, not in his engineering operations, but in finding some book on mining engineering. Without informing his friends of his embarrassments, he procured a work on coal mining, and returned at once to the mine, where he shut himself up for several weeks, while preparations were going on in the shaft, and spent days and nights in studying the application of pumping engines to mining purposes.

With his limited acquirements he found this hard work, but when the mine was ready he was also prepared, and putting on his oiled-cloth overalls, he went down the shaft and proceeded successfully and triumphantly with his work. In due time he finished his task and returned to his employers. "But," said he, "I never told them how I was enabled to do it; though ever since that time I have had great respect for scientific books. My only regret is that I know so little of them, and that I had not a good scientific education to start with."

2. By the other system or course of preparation, a young man begins his career under instructors who are personally interested in his advancement, and who acquaint him with text-books by which he not only

acquires a thorough knowledge of the principles of his profession, but also of the rules of their application under all ordinary circumstances. He begins with *drawing* and *mathematics:* the first, an art as indispensable to the competent engineer, as tools to a mechanic; the second, a written language by which alone he can treat problems of mechanics in a practical manner, and reason upon them with definiteness and precision. He is made familiar with the principles of all the sciences which bear upon his profession, and learns how readily to apply them.

Through the written experiences, deductions, and classifications of the most eminent writers, he is made acquainted with their applications in a variety of forms greater than would occur to him in a lifetime of practice.

He is furnished with opportunities of studying not only the detailed construction of all classes of machines, but also the arrangement and adaptation of the same to every variety of useful work; and thus possesses the advantage of a kind of practice superior to that of the workshop.

But the chief advantage of the course of scientific instructions lies in the thorough knowledge acquired of the applications of *Dynamical Science.* There are no problems which require a higher degree of mental culture and acquirement, nor more profound and concentrated reasoning, than some of the problems of dynamics which arise in the modern practice of this profession.

The questions connected with the dynamical theories of heat employed as a source of power;—the propulsion of ships by steam, the movement of heavy railway trains, the raising of water, the construction of heavy steam and water-wheel machinery for rolling mills, forges, and factories—all involving the movement of heavy masses, and the overcoming of corresponding resistances—are subjects which can be successfully treated only by the most rigid applications of the principles of mechanics.

This is a branch of the profession which no amount of practice alone can reach. Sooner or later, every one who aspires to become a consulting engineer must devote himself to the study of the laws, theories, rules, and formulæ, which constitute this science.

Connected with the dynamical problems which belong to the motions of masses, and the transmission of power, there are necessarily involved at every step in practice, important questions relating to the forms and strength of those parts of engines and machinery by which this transmission of power is affected, or by which heavy masses in motion are sustained in their relative positions.

On the proper proportions and dimensions of these parts depend not only the entire economy of first construction (a most important and vital consideration), but also the safety and durability of the machinery, and often the entire success or failure of business enterprises.

How many business men have felt the pecuniary consequences of the breaking down of the machinery of steam-ships, mills, or factories, in which their capital was invested, through errors or mistakes of judgment in determining the dimensions and strength of some important part of such machinery!

Unfortunately too many instances will suggest themselves to men who have been engaged in commercial or manufacturing operations, and the subject is not always an agreeable one to dwell upon. In such cases of damage to machinery it is not always the cost of reconstruction, or repairs, that causes the greatest loss, but often the entire stoppage of a business undertaking for days, weeks, and even months.

On the other hand, how often has every manufacturer of heavy machinery seen thousands of dollars thrown away in surplus or unnecessary material introduced through ignorance or want of exact calculations of strength—carrying with it all the profits of manufacture—or has been obliged to witness the throwing of tons of finished work into the scrap-heap, on account of failure in determining proper proportions or dimensions by subordinates entrusted with this duty.

Between excessive dimensions on the one hand, and inadequate proportions on the other hand, there is no chance or scope for the "rule of thumb"—there is no resource or safety but in rigid mathematical solutions and determinations.

No better illustrations can be given, perhaps, on these points, than the use of two simple but important forms or pieces in nearly all machines: the *revolving shaft*, and the *beam*.

The shaft is a piece or part of a machine which in some cases may have no other office to perform than the mere transmission of motion, while in others it may be required to transmit not only motion but pressure, amounting in some cases to hundreds of tons. How shall the proper dimensions of a shaft, for a steamship for instance, be determined which must transmit such a force? It is easy to perceive that its magnitude must be great, but no effort of judgment nor of the imagination can fix definitely the proportions; nor are there any rules of practice by which they may be determined, except those derived from the laws of mechanics, applicable to this problem, which are the results of theoretical and experimental investigations. And there is no other mode of applying these rules than by the aid of mathematical language and formulæ. Failures to apply these laws of mechanics—first to determining the strains to which shafts will be subjected, and then to adapting the dimensions and strength necessary to resist these strains—have doubtless caused many disasters to steamships; although it must be said that in very large shafts a difficulty of another character has been met, which is not easily overcome, and which forms one of the unsolved problems of mechanical engineering—the difficulty of producing perfectly homogeneous forgings in such large masses.

The *beam* is another illustration of the same character. In some machines, such as the hydrostatic press, for compressing cotton, for expressing oils from seeds, and for other purposes, short beams are often exposed to such enormous pressure that the breaking of such beams is of common occurrence, giving rise to serious interruptions and losses.

The same piece expanded in length, may sustain the walls of a building, and still further extended and composed of many pieces, it may constitute an iron bridge, of many hundred feet span.

In all these uses of the beam, the same general principles are applicable to the determination of dimensions and proportions; and although it is apparently the most simple element or piece in all machines or structures, yet there is none which so absolutely demands the aid of applied mechanics in every separate case of its adaptation.

There are many young men throughout the country who desire to become mechanical engineers, who have serious doubts in regard to the best course of preparation to be followed, and these illustrations are given merely to show in what particulars, even in the most simple parts of machinery, practical experience and observation alone are often insufficient.

It is not contended that theoretical instruction alone will make a competent engineer, nor that practical men possess no advantages in qualifications that may not be learned from books and instructors. On the contrary, there is much to be learned that can only be acquired by practice. The important conclusion at which we must arrive is that thorough scientific preparation should *precede* practice.

This is the only true solution of that important question which has led to so much controversy, how to harmonize *Theory* and *Practice.* It must be understood and accepted that practice in any profession is essential, and necessary to excellence—but this is the business of life. There is no short road to it. As long as the life of a professional man may last, he will find new problems to solve, new cases requiring the original applications of the principles of his profession. And no greater fallacy has ever obtained credit, than that which presumes that what must be the work of a lifetime, may be acquired in three or four years of youthful practice.

On the other hand, every problem which occurs in practical life, in any profession, involves the application of a set of general principles or laws, and demands certain acquirements, which may be thoroughly mastered during the period allotted to academical instruction; and without these acquirements eminence is unattainable. By such a course a young man finds himself, it is true, at the end of his academic career, without practical experience; but he may rest assured that in the mere question of time he has lost nothing; and if he will but resolutely and modestly begin life, in the lowest subordinate positions, if necessary, he will have secured all the requisites for rapid advancement to the highest spheres of usefulness and eminence.

3. Suggestions in Regard to a Course of Study.

We may now consider what should be the course of study and preparation for the attainment of the objects aimed at in the profession of Mechanical or Dynamical Engineering.

From the nature of these objects the course may be easily and definitely marked out; and it will be found sufficiently comprehensive to occupy every available hour of three or four years of faithful application, and of such variety as to excite the increasing interest and ambition of every student who may follow it.

The first, though not the most difficult subject which demands attention, is drawing. All are aware that this is merely an auxiliary art, but it is one which is indispensable.

It is impossible to design complicated or even simple machinery, and to present the ideas involved to the workmen who are to execute it, without carefully prepared drawings.

But more than this, the drawing-board of the engineer is a help to his thoughts. While the main ideas involved in a machine are first derived from the operations of the intellect, brought out perhaps by mathematical calculations, all the minor details and proportions of the parts can be properly studied only by graphical representation. The dimensions and strength of the various pieces are often suggested by the relations which are brought out in the drawing; and the conceptions of the mind are verified or corrected as the work progresses.

Moreover, the solution of many of the problems of *applied mathematics* which occur in constructions, may be most readily accomplished graphically. The instruction in this subject should be unremitting and progressive, so that at the end of the course the student may make designs and working drawings without special effort of the mind or imagination, but with readiness and accuracy.

It is unnecessary to dwell on the importance of the study of pure mathematics. As it is the foundation of all the applications of Mechanics, and largely of applied Physics, it is eminently a practical science, and as such should be thoroughly studied. Fortunately, for the ordinary and usual cases of practice, the more difficult branches are not so essential, and there is no reason why the student should not mainly devote his time to gaining, by constant daily drill, that kind of mastery over the practical branches of the subject that will enable him to make use of his knowledge with readiness and facility.

He will find in the applications of this science to mechanics, and in the applications of mechanics to machinery, constant use for the elementary theorems and principles of algebra, plane, descriptive, and analytical geometry, trigonometry, and calculus; and the knowledge of these subjects should be, if possible, as familiar to him as his mother tongue.

The *Science of Mechanics* is that which furnishes the fundamental principles and laws on which the profession of Mechanical Engineering is based.

It may be presented to the student in two aspects: first, as a Natural Science capable of explanation and comprehension in ordinary language. In this view its principles are apt to make the strongest impression and to be most easily remembered. Second, as a preliminary to practical applications, however, it is necessary to treat this subject mathematically; and in *analytical mechanics*, we have the most beautiful, useful, and instructive illustration of applied mathematics.

It is important that this science should be thoroughly understood independently of its practical *applications*. These various applications constitute a separate branch of study which has been denominated APPLIED MECHANICS.

This branch of science involves elements of knowledge which cannot be derived from theory alone.

When the exact principles and formulæ of pure mechanics are applied in special cases to the various problems of practice, it is found that these formulæ require modification. All motions of bodies, for instance, take place in resisting media, air, or water. The physical properties of bodies interfere with the exactness of the results of purely theoretical deductions. The properties of strength, hardness, elasticity, cohesion, and the laws of friction, are subject to change, with circumstances of use, temperature, and various other causes; so that an extensive range of experimental results, the fruits of laborious investigations and observations, must be combined with theoretical principles to produce rules of practice.

Moreover, analytical mechanics treats of forces, masses, motions, and the relations between them, in an abstract manner, without reference to real magnitudes or sensible objects; while in applied mechanics, forces become pressures, resistances, strains, or tensions which arise in the utilization of materials or of power; and problems involving heat, weight, inertia, velocity, cohesion, and friction, must all be solved by regarding these as quantities to which numerical values must be given, and which may be weighed, measured, or calculated, each by its own special unit.

This combination of theoretical mechanics with the results of experiment, and the application of general laws to special cases, constitutes the subject of applied mechanics.

Inasmuch as it is a subject of particular applications, instruction in it must embrace many of the features of actual practice, between which, and pure theory, it is the connecting link.

Besides the mathematical sciences there are others, a knowledge of which may be regarded as essential. The Mechanical Engineer is obliged to deal exclusively in operations which involve the use or control of the elements and materials which are found in nature. The conversion of some of these elements into special forms for use; the employment of others, such as fuel, air, and water, in the development of power; the reactions which some of these elements undergo when brought into contact with each other; the deterioration of others from use; and their physical properties as to strength, or durability; all these considerations make it essential that the Mechanical Engineer should possess a thorough knowledge of Chemistry, of Physics, and of Metallurgy. Indeed there is scarcely an instance where large operations are performed by machinery, where the combined use and applications of all these sciences with those of mechanics are not in some way exhibited.

As regards the course of study, it is thus evident that there is hardly a profession which requires more thorough and varied preparation than that which has for its object the application and uses of machinery.

4. Fields of Usefulness.

The fields of useful employment open to young men who may have reached the high degree of proficiency attainable, under the course of instruction thus described, are varied and extensive. It is a mistake to speak of machinery as *labor-saving;* it is *labor-multiplying* in its effects, and demands of the laborer merely increased intelligence, the use of the intellect rather than the wear and tear of muscles; and the products of a man's labor no longer depend solely on physical strength, but upon the efficiency of the tool or machine placed in his hands, and his skill in using it.

The steam and water power of this country now in use are probably equivalent to the power of one hundred millions of men. The applications of such enormous aggregates of energy require corresponding amounts of invested capital, and the employment of large numbers of men of more than ordinary skill and intelligence in the designing, manufacturing, and controlling of the machinery so extensively used. And one of the pressing wants of our country at this time is the need of more young men of a higher standard of qualifications for these pursuits.

For particular fields of usefulness we may point to the construction and management of steamships, both for government uses and for the merchant marine. The entire revolution in ship-building by which iron has supplanted wood, throws all the opportunities and advantages of this extensively practised art or industry within the sphere of the Mechanical Engineer.

The modern steamship embodies more than any other structure of the present day all the principles and practices of mechanical and dynamical science, and there is no class of structures in which science as well as practical skill is more positively demanded. Many millions, perhaps hundreds of millions of dollars, must be expended in future years to meet, in this country, the growing wants of our naval and merchant services.

Another important sphere of usefulness may be found in the application of steam power to works of internal industry, to railroads, manufacturing establishments, mines, &c. Works for construction of engines and machinery are scattered all over the land, embracing every conceivable variety.

Other establishments adopt for special trades or business operations the construction of iron bridges, and the application of iron to buildings, two fields of employment for labor and capital which are rapidly increasing and extending; and in which the Mechanical Engineer shares with the Civil Engineer and Architect the labor and credit of planning and erecting the beautiful structures of iron which are beginning everywhere to spring into existence.

The improvement of water power by the use of turbine-wheels, and the manufacture of these important prime movers have already become a very large and valuable branch of manufacturing industry, requiring many millions of capital. More than one manufacturer in this branch of business has expressed to me his full and hearty interest in the movement which is here being made, for the better scientific education of young men who may become available for this work.

Where so much machinery is constructed and used, there is of course a large demand for raw materials, especially iron and steel. The works which supply these materials, the furnaces, forges, and rolling mills, occupy also a large place in business enterprises. To these we may add the mills and manufacturing establishments, which are scattered thickly through the land, requiring superintendents, managers, consulting engineers, and *experts*, and we shall still have an incomplete review of the many channels in which graduates in this course may find occupation.

This statement requires, however, a condition on their part; a condition that there shall be in their acquirements nothing superficial nor unreal; but those solid attainments which come from faithful and persevering application. With these, the number of graduates that may leave this institution cannot be too great. They will be quickly absorbed in the great industries of the country.

5. Benefits to the Public.

The welfare and the success of the young men who shall receive the advantages of this superior scientific training are not, however, the only, nor indeed the most important matters for consideration.

What return or compensation shall there be to the public and to business communities for their sympathy, co-operation, and aid in establishing these special courses of instruction; and what may they expect and receive for the price paid for these higher scientific acquirements?

There is another side to the account on which the balance of advantages should largely rest.

Leaving out of view the pecuniary gains to individuals and associated companies engaged in commerce, the arts, and manufactures, which must result from the employment of men of higher qualifications, there are other considerations of still higher value.

While the use of machinery in multiplying human labor, and in producing great and special results which without it would be impossible, has produced means of comfort and happiness which belong to what we call a higher civilization, it is not to be forgotten that in order that the masses—the poorer and middle classes, as well as the rich—may partake of these new blessings, the price to be paid for them must not be beyond reach.

The condition that the greatest possible number shall be able to avail themselves of the opportunities of quick transportation by sea and land, and that the necessities of comfortable living shall be transported and distributed widely, and with rapidity, carries with it the requirement for economy in the construction of steamships and railroads, and in the use of steam as a motive power.

The condition that every human being may learn to read and derive pleasure and profit from books, carries with it the necessity for economy in all that relates to the art of printing.

The condition that iron and steel may be employed so largely for public and private use, requires that they shall be produced with the least possible expenditure.

The condition that every man may place his family in a comfortable dwelling, and give them warm and suitable clothing, the luxuries—if we choose to call them so—of carpets, ornaments for his dwelling, agreeable furniture, abundance of light and heat; and above all, the condition of things which enables all, after having provided these comforts for themselves and families, to contribute of their *savings* to the wants of the unfortunate; to sustain charitable and benevolent enterprises, to build hospitals and asylums, to send the Gospel to the heathen—requires that the arts, industries, and manufactures that produce these results shall be conducted with careful saving and the least possible waste.

To aid in the accomplishment of these great ends is one of the objects of applied science. From the days of Watt to the present time, the main object of the application of science to the construction and use of the steam-engine has been the economy of fuel; and the triumph of Bessemer consists in his having shown how to economize the production of steel on a large scale.

And generally the aims of applied science are mainly to show how to avoid *waste*, to discover and point out the means by which useful results may be accomplished with the least expenditures—to teach *economy of time*, *economy of labor*, *economy of materials*, *economy of power*, and saving of *health* and *strength*.

In this field, Mechanical or Dynamical Engineering has its important part to perform in the advance of Christian civilization.

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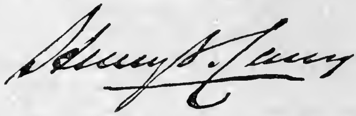

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